

SINGLE SHIP ROUTING

by

Willard Evan Bleick

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## SINGLE SHIP ROUTING

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Academic Dean

ABSTRACT:

This report presents an operational computer program for the minimal-time routing of single ships. Although written specifically for VC2AP3 and VC2AP2 vessels operating in a described area of the north Pacific ocean, the program can be modified easily to provide routes for other type vessels in any ocean area of the northern hemisphere. The method of incorporating weather forecasts into the preparation of minimal-time ship routes is described, and possible future developments are discussed.

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## I. Introduction.

Section II, by Prof. G. J. Haltiner, describes the scheme of incorporating weather forecasts into the preparation of minimal time ship routes used in this report, and discusses possible future developments. The remaining Sections of the report extend the previous work of Profs. W. E. Bleick and F. D. Faulkner, [1] and [2], by describing an operational computer program for the minimal-time routing of VC2AP3 vessels in a specific area of the north Pacific ocean. A subroutine for AP2 vessels is provided which can be substituted for the AP3 subroutine in the program. The program can be adapted to routes in other ocean areas of the northern hemisphere by changing the Fortran statements on a very small number of cards listed in the Appendix. Some suggestions are made for improving the program.

## II. Use of Long-Range Weather Forecasts in Ship-Routing.

1. The scheme of incorporating weather forecasts into the preparation of the minimal-time ship routes of this report consists of the following parts:

- a) The Fleet Numerical Weather Facility prepares operational wave predictions for periods up to 48 hours. These predictions for 12Z and 24Z of 26 and 27 July 1966 were used for the first two days in the ship voyage example of this report.
- b) The Weather Bureau's 5-day surface pressure forecast was used for the next three days. This forecast, which is prepared every Monday, Wednesday and Friday, consists of one sea-level pressure map per day at 1230Z. Lieutenant D. M. Truax USN [3] used these maps, in a Master of Science thesis project supervised by Prof. Haltiner, to determine the surface winds and, in turn, to calculate the height, period and direction of the wind waves and swell. This calculated data was used at 12Z on July 28, 29 and 30 of the ship voyage example of this report.
- c) The Weather Bureau 30-day forecast was utilized for the remainder of the ship's voyage. Although not published for use outside the Weather Bureau, a copy of the 30-day predicted

mean sea-level pressure map, centered at the middle of the month, was mailed to Prof. Haltiner for the ship routing experiment. Lieutenant Truax [3] estimated surface winds from this single map, and again the wave conditions were calculated. These calculations were repeated on a daily basis using the same map for the remainder of the total forecast period. Since the same winds are used repeatedly during the latter part of the period, the forecast waves reach a steady state within a few days. This steady state forecast was used at 12Z of July 31 and all subsequent days of the ship voyage example of this report.

2. The predicted 30-day mean pressure chart has relatively weak pressure gradients, as would be expected from the averaging process. In contrast, the individual daily charts which make up such a mean have strong gradients in general, particularly in the vicinity of the migratory cyclones or low pressure areas. These systems have strong winds and high seas associated with them, which are reflected in the 30-day mean only in a very limited fashion. The forecast procedure outlined in paragraph 1 did, however, show considerable skill over the use of long term monthly mean charts. Nevertheless it is desirable to seek additional ways, possibly more accurate, of providing wave estimates for the latter part of a voyage extending beyond a 5-day period. One possibility, which appears to have promise, is to develop a wave climatology. This could consist of utilizing the wave analyses now being prepared daily at FNWF to compute mean wave height, direction and period as a function of latitude and longitude for each month of the year. These data could then be compared with those derived from the Weather Bureau 30-day sea level pressure forecasts in order to ascertain the best source of wave data for trans-oceanic ship routing. Such a wave climatology would have other applications in Naval operations as well. A further refinement in the development of a suitable wave climatology for use in ship routing might consist of the preparation of mean wave char-

acteristics not only as a function of latitude, longitude and month, but also separated according to weather type. The latter are determined largely according to the main storm tracks which vary from week to week as well as with seasons. Such a climatology would obviously take more effort to prepare, but would be a very valuable aid in ship routing.

3. Finally, it should be mentioned that a number of groups are experimenting with long-range weather prediction by numerical integration of the hydrodynamical equations. It is expected that eventually such predictions will show skill for perhaps several weeks, and thus day-by-day wave forecasts could be made available for the entire period of a trans-oceanic voyage.

### III. Input and Output of the Computer Program.

1. The program VC2AP3, page 20 of the Appendix, was written for the Control Data Corporation 1604 computer in Fortran 1963, which is their version of the IBM Fortran IV. The  $63 \times 63$  grid of the northern hemisphere stereographic projection of the Fleet Numerical Weather Facility was used to specify the location of the ocean wave data as explained in [1] and [2]. It was desired that the 32764-word memory of the CDC 1604 contain wave data for as large a part of the  $63 \times 63$  grid as possible in order to take advantage of high-speed random access to core memory. This was accomplished by packing the floating-point wave height  $H$  and wave direction  $K$  at a grid point into a single computer word, with height in the upper half and direction in the lower half word. Program TAPE, page 33 of the Appendix, describes how the fixed-point FNWF wave field data was transformed to packed floating-point form. The conversion of the right-shifted FNWF fixed-point data to floating-point was accomplished by hardware features peculiar to CDC computers, and probably not existing in IBM computers, involving normalization by addition to fixed-point octal 2000000000000000 followed by addition to floating-point zero. The packing and subsequent unpacking was accomplished by CDC Fortran 1963 operations. The right or left shifts involved were simulated by division or multiplication by the integer 16777216

decimal. The packing and unpacking also used a CDC Fortran 1963 masking operation which does not exist in IBM Fortran IV.

2. The grid wave data magnetic tape output of program TAPE is read as input from Logical Tape Unit 1 by the main program VC2AP3. It is stored in core memory as the three-dimensional MHD array of DIMENSION (18,32,8) with a total of 4608 words. The dimensions 18 and 32 correspond to FNWF stereographic projection plane grid point indices of  $8 \leq i \leq 25$  in the direction of the 10E longitude meridian and  $16 \leq j \leq 47$  in the direction of the 100E longitude meridian. The dimension of 8 corresponds to the time series of predicted wave fields as described in Section II, page 3, for 12Z and 24Z of 26 and 27 July, 12Z on July 28, 29 and 30, and the final steady-state forecast used at 12Z of July 31 and all subsequent days. The 18 by 32 rectangular field of data is shown on the map of Figure 1, page 8. The ship routing program will not work unless all points of the ship route, including the initial and terminal points, are within a smaller 16 by 30 rectangle also shown in Figure 1, defined by  $9 < i < 24$  and  $17 < j < 46$ . A local coordinate system for the rectangular array is set up in the VC2AP3 program with the origin 0 at  $i=7$  and  $j=15$ , with the  $O_x$  and  $O_y$  axes in the direction of increasing  $i$  and  $j$  respectively. The smallest values of  $x$  and  $y$ , corresponding to  $i=8$  and  $j=16$ , are therefore  $x=1$  and  $y=1$ .

3. The MHD array of wave data in core memory may be extended from the present 4608 words to a maximum of 21156 words to accommodate a larger ocean area or a longer time series, or both. This is accomplished by the relocation of COMMON feature of Fortran 1963 by using the following cards after the MCS control card:

- BINARY,56. (The dash in column 1 is a 7 and 9)
- RELOCOM. (The dash in column 1 is a zero, 7, 9 and minus)
- FTN,L,A,E. (The dash in column 1 is a 7 and 9)

and replacing the -EXECUTE. card by -EXECUTER. A change in the present geometric dimensions and/or origin of the MHD array must be accompanied by rather obvious changes in certain cards of programs TAPE and VC2AP3. A list of the cards requiring a change is

given on page 36 of the Appendix. A change in the time dimension of the MHD array, corresponding to an increase in the length of the time series, must be accompanied by rather obvious changes in cards 382, 394 and 399 of subroutine TERP, with card 404 being changed to IF (L-5) 14,5,5. An increase in the time dimension requires changes in cards 13 and 85 of program TAPE, and in the format statements of cards 18, 21, 52, 55, 64 and 67.

4. The first two of the BCD punched card input to the program VC2AP3, following the -EXECUTE. card, contain the data:

Card 1: First line of the TI=IT title in format (6A8/) for the map produced by subroutine DRAW in Statement 11. See example on page 32 of the Appendix, and explanation of the DRAW subroutine on page 37 of the Appendix.

Card 2: Format (8A8,I3) of which 6A8 is the second line of the map title TI. The remaining part of the format is A8 for the DATE=KATE of the routing computation, A8 for eight blank Hollerith characters for a null label AL=LA on the map grid plot, and I3 for the NST total number of ships to be routed by the program. The DATE of the routing computation corresponds to the 12Z hour of the first member of the time series in the MHD array. See example on page 32 of the Appendix.

Following these two BCD cards there are groups of either 6 cards or one card for each ship routed by the program, depending on whether or not the option to plot an earlier route of a particular ship is elected.

Card 3: Format (A4,2A8,F3.0,F6.1,F5.1,F6.1,F5.1,F3.0,I1,2I2,I1,F8.5,F6.3) with example on page 32 of the Appendix. The first A4 is the GL=LG ship identification number with column 1 of the card blank, used by the DRAW subroutine to label the terminal point of a ship route. The first A8 is the DATEX=KATEX date on which the ship leaves the initial point of its route. The second A8 is the FL=LF Julian date of departure, with blanks in columns 17 to 20 inclusive, used by the DRAW subroutine to label the initial point of a ship route. The F3.0 is the HR hour of ship departure from its initial point measured from 12Z on the DATE of routing, i.e. from the 12Z hour of the first member of the time series in the MHD array. The F6.1, F5.1, F6.1, F5.1 formats are the longitudes and latitudes of the initial and terminal points of the route, XLG1, XLT1, XLG2, XLT2, with the longitudes considered positive if east of the Greenwich meridian. The F3.0 format provides for the RMUL convergence factor discussed later on pages 11 and 16. Note the absence of a decimal point in the example on page 32. The I1 for-

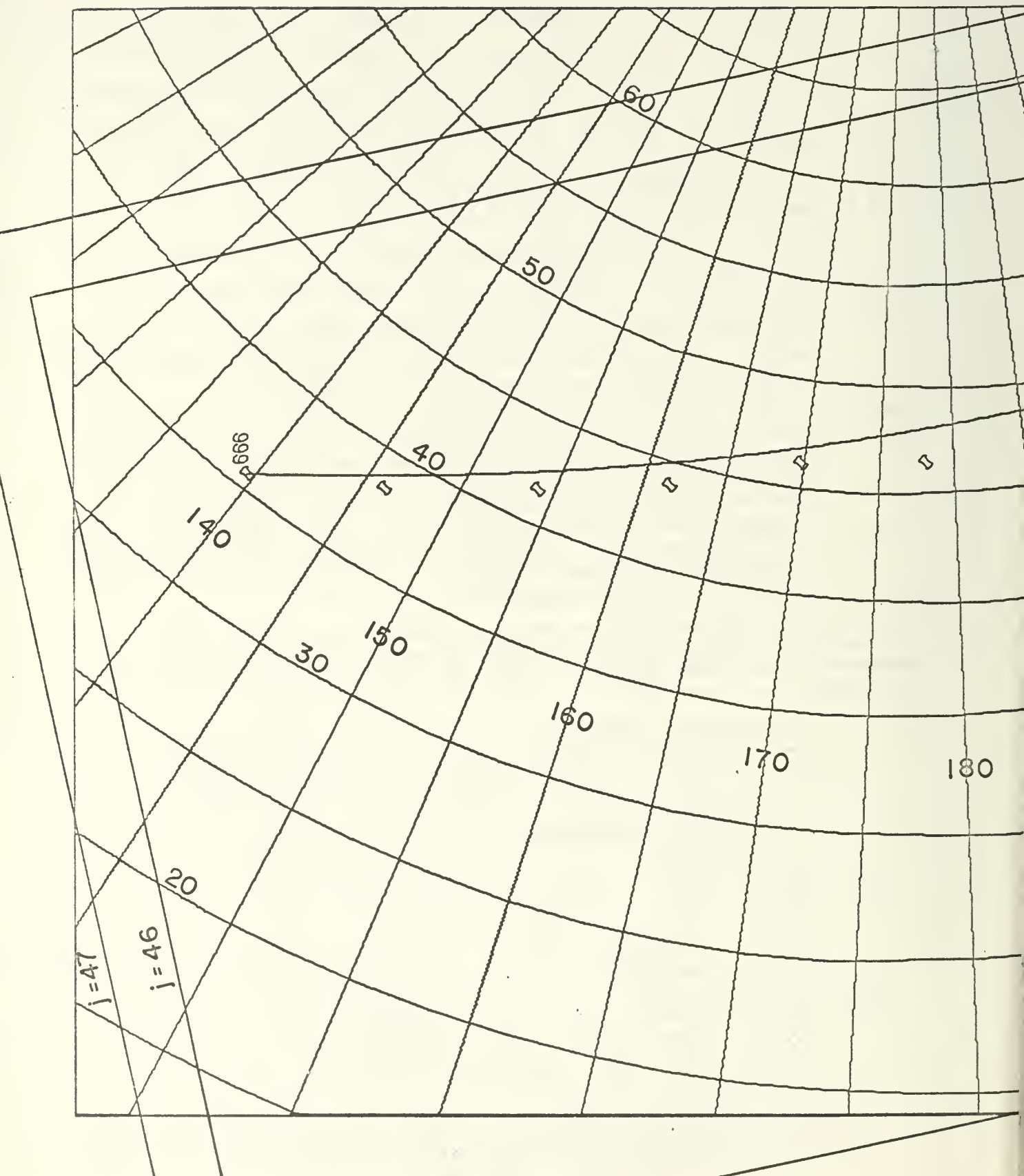


FIG. 1. (Left side). J207 day route of ship 666.

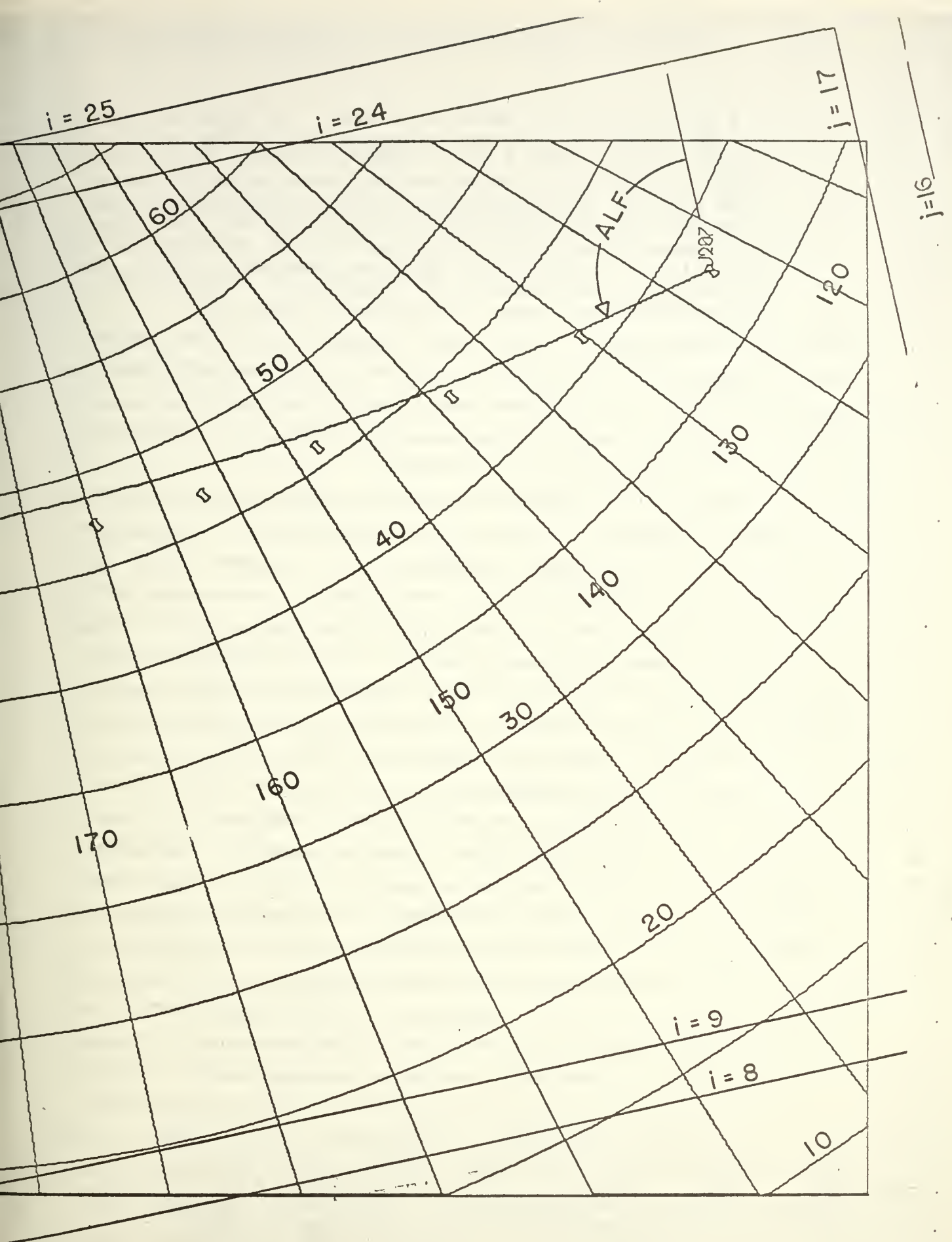


FIG. 1. (Right side). J207 day route of ship 666.

mat provides for NN which is either 1 or zero according as the option to plot an earlier route of the ship is or is not elected. The first of the 2I2 format is for the NSTEP reciprocal of the time step used in the integration process, with 24 of the example indicating a time step of 1/24 of a day. The second I2 format specifies the number LMAX of iterations allowed in determining the minimal-time route. The remaining formats I1, F8.5, F6.3 provide for the variables NP, PALF and PT used in an option described later in Section IV, page 13.

Card 3 is followed by five BCD cards punched out by the statements on cards 334 to 338 of an earlier use of program VC2AP3 if the option NN=1 to plot an earlier track of the ship has been elected. If NN=0 on card 3, the remaining BCD cards of the input deck refer to other ships to be routed.

5. The output of the program is a map grid for each vessel routed, shown in Figure 1, produced by the CALL DRAW of statement 11. The details of subroutine DRAW are given on page 37 of the Appendix. If the option NN=1 has been elected, statements 16 to 18 cause an earlier route of the ship to be plotted as in Figure 2, using plus signs for daily positions and an identifying Julian day mark for the initial point. Statements 19 to 44 cause a geodesic route for the ship to be computed and plotted as a solid line. Figures 1 and 2 give examples of this with the ship's angle of departure ALF, measured counterclockwise from the 0x axis, also indicated. The terminal point of the geodesic route plot is marked by the GL=LG identification number of the ship. The purpose of the geodesic route computation is to find first approximations to the time T and angle of departure ALF used in the LMAX iterations toward a minimal-time route of statements 45 to 69. The computation of the route is abandoned if any point of the geodesic route falls outside of the rectangle  $9 < i < 24$  and  $17 < j < 46$ , but the geodesic route within this rectangle is plotted on the map grid. The minimal-time route computation is initiated by statement 45 only if the entire geodesic route has been computed successfully. The format of statement 71 is printed if the LMAX iterations result in a ship route terminal point more than 100 nautical miles from the desired destination, together with



PRINT output for J207 day route of ship 666.

TOTAL NUMBER OF VC2AP3 SHIPS ROUTED = 1  
CN JUL26,66 FROM 12Z TO 24Z, AND CN FOLLOWING DAY FROM 00Z TO 11Z

ROUTE OF SHIP 666 BEGINS ON JUL26,66, JULIAN DATE = J207,  
0 HOURS AFTER 1200Z CN JUL26,66

FROM LONGITUDE = -122.5 AND LATITUDE = 37.9  
TO LONGITUDE = 139.6 AND LATITUDE = 35.6

RMUL= 10 LMAX= 7 NSTEP=24 NN=0 NP=0

L	N1	ALF	T	X(N1)	XFIN	Y(N1)	YFIN
0	288	1.81954	11.949	13.778	13.778	28.357	28.357
1	288	1.81954	11.949	14.613	13.778	28.159	28.357
		1.82360	11.944				
2	288	1.82360	11.944	14.254	13.778	28.212	28.357
		1.82600	11.953				
3	288	1.82600	11.953	14.054	13.778	28.311	28.357
		1.82731	11.930				
4	288	1.82731	11.930	13.782	13.778	28.368	28.357
		1.82731	11.924				
5	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				
6	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				
7	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				

DAYS OF TRAVEL	LONGI- TUDE	LATI- TUDE	WAVE HEIGHT	WAVE DIRECTION FROM NORTH
0	-122.5	37.9	6	354
1.00	-130.3	41.1	5	11
2.00	-138.9	43.8	2	191
3.00	-148.2	46.0	5	156
4.00	-156.9	46.7	21	177
5.00	-164.9	47.3	21	165
6.00	-173.1	47.3	21	164
7.00	178.2	46.5	18	122
8.00	169.7	46.1	19	146
9.00	161.6	43.8	13	124
10.00	154.0	41.6	17	357
11.00	146.1	38.5	10	116
11.92	139.6	35.6	-1	2

GRAPH TITLED  
JOB 0574  
VC2AP3  
HAS BEEN PLOTTED.

BLEICK  
DECEMBER 6

BOX 6  
1966

some later plot of the track if the NN=1 option of card 33 of the program is elected in a later routing of the ship. The card 339 statement causes the daily track positions to be plotted on the map grid by diamond-shaped symbols, as in Figure 1, with the LF=FL Julian day identification of the initial point. Statement 80 continues the M=1,NST loop to proceed with the routing of the next ship.

#### IV. Example of Options NN=1 and NP=1.

An example of the use of the NN=1 option is given in Figure 2 where the Julian J207 day route of ship 666 is plotted with plus signs. The ship had departed considerably from its J207 routing during the first 24 hours and required a new route from longitude -130.0 and latitude 35.0 starting at 12Z on Julian day J208. It was necessary to resort to the simulation of putting HR=24 on this new route since a new time series MHD array starting at 12Z on J208 was not available. Considerable difficulties were encountered in computing a global-extremum J208 day minimal-time route. The angle of departure ALF generated by the geodesic route computation may have bias to the extent that successive track iterations always go around a storm area on the same side, when actually the other side would be a better choice. The geodesic track time was T=11.385 days and angle of departure ALF=1.73554 radians. This ALF was a poor initial approximation to that required for the final successful minimal-time route of Run 3, as indicated by the successive runs of the following table:

Run	NP	Type of Route	Graph mode Fig. 2	RMUL	LMAX	NP=1 PALF	input PT	Converged VC2AP3 ALF	output T
0		Geo- desic	Solid line					1.73554	11.385
1	0	Local extreme	Dashed line	10	10			1.749	11.567
2	1	Local extreme	Dashed line	4	6	1.81200	10.967	1.814	11.682
3	1	Global extreme	Diamond symbols	999	7	1.90000	11.250	1.90003	11.264

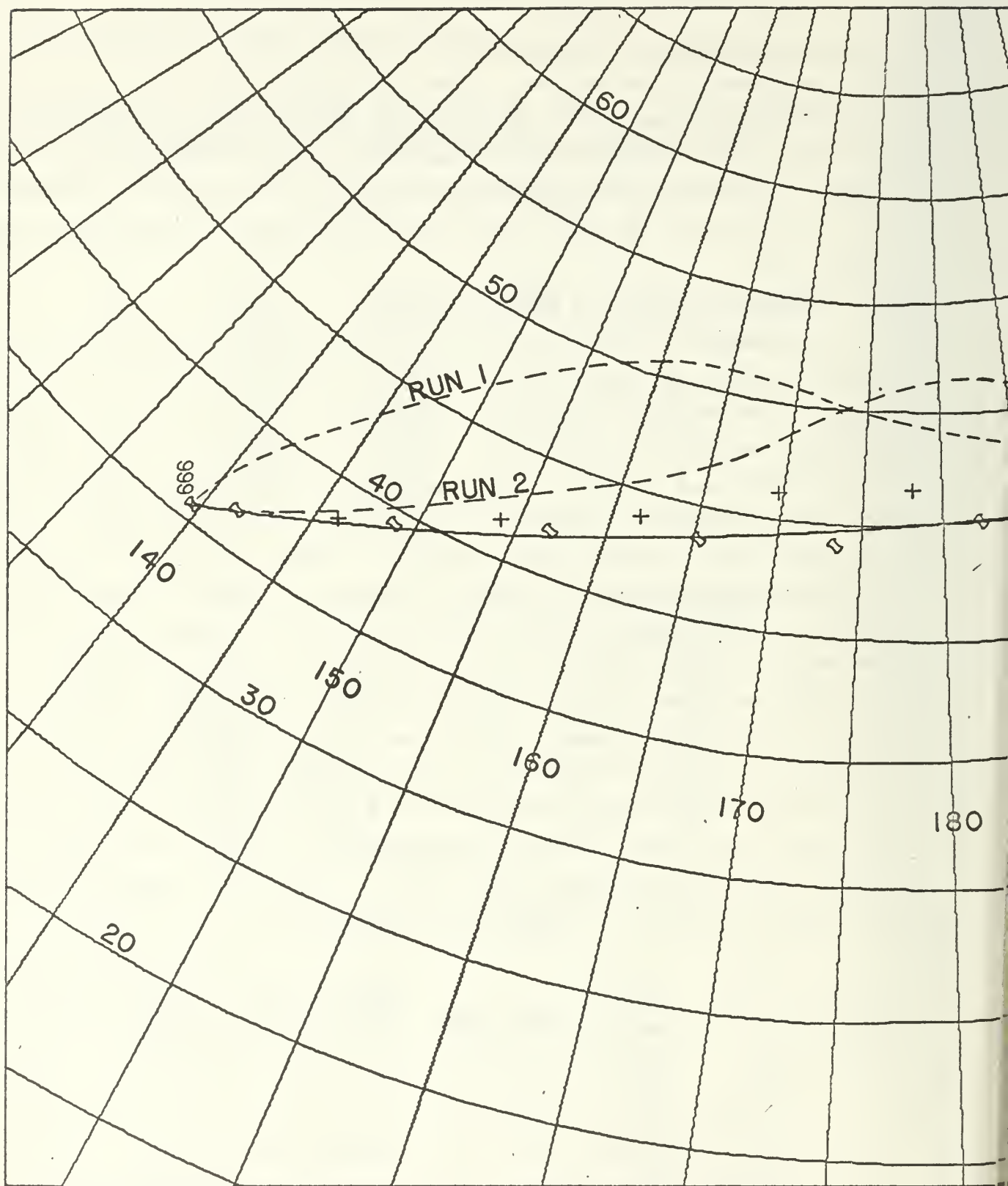


FIG. 2. (Left side). J208 day route with options NN=1 & NP=1

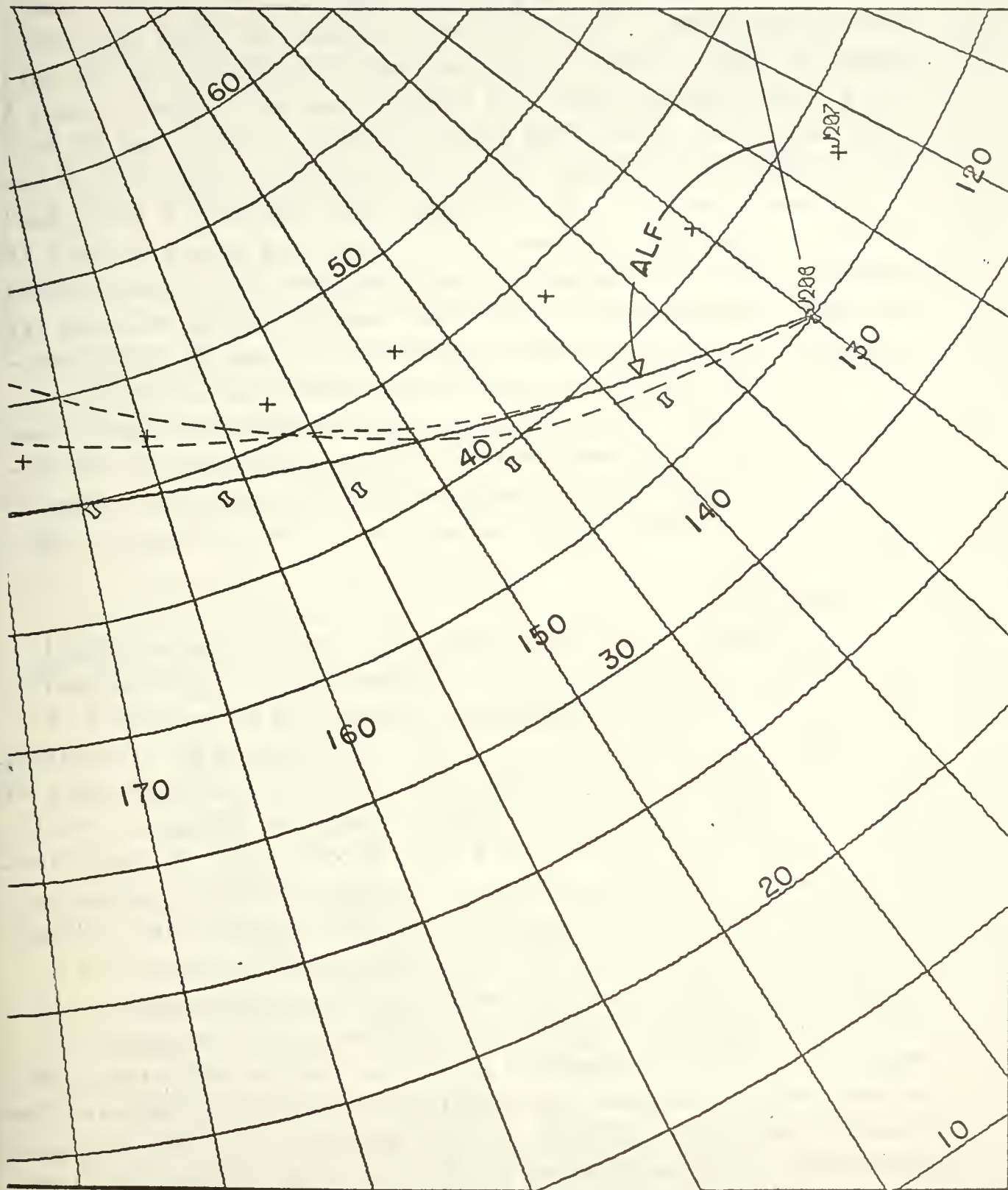


FIG. 2. (Right side). J208 day route with options NN=1 & NP=1  
-15-

The program VC2AP3 provides the option to override the values of ALF and T generated by the geodesic route computation by using NP=1 in column 54 of the first ship-related IBM input card described on page 7, and to start the LMAX iterations with the values ALF=PALF (format F8.5) and T=PT (format F6.3) from columns 55 to 68 inclusive of this IBM card. The values of PALF and PT in Runs 2 and 3 of the above table were chosen by inspection of the iterations produced in earlier runs. Note that Runs 1 and 2 converged to local time-extremal routes requiring more time than the geodesic route. The successful Run 3 required the input RMUL=999 and PALF=1.90000 radians, the former probably being somewhat larger than really required for convergence. The nearby input RMUL=100 and PALF=1.90000 were tried without obtaining convergence. The extreme value of the convergence factor RMUL=999 used in Run 3 and the resulting sensitivity in the required value of the input angle of departure PALF suggest that the non-linear terms neglected in the Newton-Raphson equations are very strong on the J208 day route.

#### V. Conclusions.

1. It is suggested that any future revision of program VC2AP3 take steps to reduce the computer running time of a trans-Pacific track iteration from the present 1 minute and 47 seconds to an attainable 13 seconds. This is accomplished easily by eliminating the calculation of 128 sine and cosine functions on each entry of subroutine TERP. Under this proposed scheme the MHD array would store a grid-point wave height H only in each word. Two additional 4608-word arrays would store the the CK and SK trigonometric functions, computed once only in a modified program TAPE. Assuming that the time dimension of these three arrays remains at 8, the CDC 1604 memory capacity would even allow the geometric dimensions to be chosen to cover 881 grid points, an increase of about 53% from the present 576 grid points of the MHD array. This proposal would eliminate the normalizing and masking hardware features of the program peculiar to CDC computers, and make the program useable in other Fortran IV systems. Even larger dimensions

for the three arrays could be achieved by using a more realistic graph plotting program to replace subroutine DRAW with its exorbitant demand for 5760 words of core memory. Care would have to be exercised in implementing this proposal since the X(900) and Y(900) arrays of subroutine DRAW are used by program VC2AP3 for other memory-conserving purposes.

2. It is suggested that any future revision of program VC2AP3 try to go beyond the present linear Newton-Raphson scheme, and attempt to include quadratic terms also. Such a change might overcome the convergence difficulties disclosed in Section IV. If such a quadratic scheme were found and used successfully, it may be possible to obtain a considerable reduction in the LMAX number of track iterations required to achieve convergence.

3. In order to reduce the amount of monitoring of output required in program VC2AP3, it is suggested that any future revision of the program attempt to include as far as possible the following recommendations of Schmieg, [5] pages 30, 31 and 37:

- a) Check the Legendre and Weierstrass<sup>conditions</sup> for a minimal-time route at each time step of the numerical integration. This check may give an automatic method of eliminating local time-extremal routes which are not the desired global minimal-time route.
- b) Examine the magnitude of the Hamiltonian at the end of each of the LMAX iterations to determine whether it has diminished from its value at the end of the previous iteration. If not diminished choose an appropriate convergence factor RMUL to get ALF for the next track iteration.

#### VI. Acknowledgements.

The authors are indebted to LT Daniel Mack Truax USN, whose Master of Science degree thesis [3] provided the predicted ocean wave fields at 12Z on July 28, 29, 30 and 31 as described in Section II, and to CDR Leo C. Clarke USN Ret. of the FNWF, who

assembled all of the ocean wave field data described in Section II on a single magnetic tape used as part of the input to the Fortran 1963 program TAPE of this report.

## VII. Mathematical Theory.

1. A misprint in equation (16) of [1] and [2] requires correction by replacing  $R$  by  $R^2$ . The  $\delta p$  of this equation is an approximation in that certain terms obtained in the differentiation of equation (10) have been dropped as being unimportant. While the approximation is useful for a short ship route, it is desirable to use the following completely accurate expression for a long trans-Pacific route

$$\delta p = \frac{1}{D} [R^2 |E| \Lambda^{-2} \delta \alpha + (V_{px} V - V_p V_x) \delta x + (V_{py} V - V_p V_y) \delta y], \quad (1)$$

where  $D = V^2 + 2V_p^2 - V V_{pp}$ . Use of this new expression for  $\delta p$  with equations (14), (16) and (18) of [1] and [2] gives the following pair of inhomogeneous differential equations as a replacement for equation (19) of these references

$$\frac{d}{dt}(\lambda_1 \delta x + \mu_1 \delta y) = \frac{R}{\Lambda D} [\lambda (V V_{py} - V_p V_y) - \mu (V V_{px} - V_p V_x)] (\lambda_1 \delta x + \mu_1 \delta y) - \sin \alpha \frac{|E|^2}{D} \left(\frac{R}{\Lambda}\right)^3 \delta \alpha \quad (2)$$

$$\frac{d}{dt}(\lambda_2 \delta x + \mu_2 \delta y) = \frac{R}{\Lambda D} [\lambda (V V_{py} - V_p V_y) - \mu (V V_{px} - V_p V_x)] (\lambda_2 \delta x + \mu_2 \delta y) + \cos \alpha \frac{|E|^2}{D} \left(\frac{R}{\Lambda}\right)^3 \delta \alpha.$$

Let  $y_7$  be a solution of either of (2), rendered homogeneous by putting  $\delta \alpha = 0$ , and with  $y_7(0) = 1$ . Then a solution of (2) with  $\delta \alpha \neq 0$ , and with vanishing initial values is

$$(\lambda_1 \delta x + \mu_1 \delta y)_T = -y_7(T) y_8(T) \sin \alpha \delta \alpha \quad (3)$$

$$(\lambda_2 \delta x + \mu_2 \delta y)_T = +y_7(T) y_8(T) \cos \alpha \delta \alpha$$

where

$$y_8(T) = \int_0^T \frac{|E|^2}{y_7(t) D} (R/\Lambda)^3 dt. \quad (4)$$

The solution of (3) gives the following new version of equations (19) of [1] and [2]

$$[\delta x, \delta y]_T = y_7(T) y_8(T) \delta \alpha [-\mu, \lambda]_T / |E(T)|, \quad (5)$$

and the Newton-Raphson equations (22) of these references are replaced by

$$\begin{aligned} \dot{x}(T) \Delta T - [\mu y_7 y_8 / |E|]_T \delta \alpha &= \Delta x(T) \\ \dot{y}(T) \Delta T + [\lambda y_7 y_8 / |E|]_T \delta \alpha &= \Delta y(T). \end{aligned} \quad (6)$$

2. The subroutines AP3 and AP2 of the Appendix are based on the work of James [4]. His speed versus wave height data for these vessels have been approximated by arcs of hyperbolas as explained in [1] and [2].

#### VIII. References.

1. W. E. Bleick and F. D. Faulkner, Minimal-Time Ship Routing (includes Fortran programs), Research Paper No. 46, 18 pages, August 1964. Replace R by  $R^2$  in Eq.(16) to correct misprint.
2. W. E. Bleick and F. D. Faulkner, Minimal-Time Ship Routing, Journ. of Applied Meteor., 4, 217-221 (1965). Replace R by  $R^2$  in Eq.(16) to correct misprint.
3. D. M. Truax, Use of Extended Range Forecasts in Ship Routing, thesis submitted in partial fulfillment for degree of Master of Science in Meteorology, Naval Postgraduate School, 25 pages, October 1966.
4. R. W. James, Application of Wave Forecasts to Marine Navigation, Naval Hydrographic Office, 85 pages, June 1959.
5. G. D. Schmieg, Optimum Submarine Routing II, thesis submitted in partial fulfillment for a degree of Master of Science in Mathematics, Naval Postgraduate School, 72 pages, August 1966.

# IX. Appendix.

```

-COOP,BOX 6,BLEICK,I/1/O/49/S/56/57/E/45=54,21,10000,0, VC2AP3 - 6 DEC 66.
-FTN,L,A,E.
PROGRAM VC2AP3
C YVARS(1)=LAMBDA1 YVARS(2)=MU1 YVARS(3)=LAMBDA2 YVARS(4)=MU2
C YVARS(5)=X YVARS(6)=Y YVARS(7)=S OR Y7 YVARS(8)=Y8
DIMENSION MHD(18,32,8),X(900),Y(900),RX(10,90),RY(10,90),
+ IT(12),TI(12),C(4),YVARS(8),YC(8),AK(4,8),DY(8)
COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,
+ A,B,CC,DA,DB,DC,LR
EQUIVALENCE (IT,TI),(LA,AL),(KATE,DATE),(LP,PL),(LG,GL),(LF,FL),
+ (X,RX),(Y,RY),(KATEX,DATEX)
REWIND 1
C(1) = 0.0
C(2) = 0.5
C(3) = 0.5
C(4) = 1.0
C READ MAP GRID DATA FOR DRAW SUBROUTINE, AND WAVE FIELD MATRIX
READ(1) X,Y
READ(1) MHD
C READ MAP TITLE, DATE OF ROUTING COMPUTATION, MAP GRID PLOT LABEL,
C AND TOTAL NUMBER OF SHIPS ROUTED
READ(50,1) TI,DATE,AL,NST
1 FORMAT (6A8/8A8,I3)
WRITE(51,2) NST,KATE
2 FORMAT(39H1TOTAL NUMBER OF VC2AP3 SHIPS ROUTED = I3/1X3HON A8,54H
+FROM 12Z TO 24Z, AND ON FOLLOWING DAY FROM 00Z TO 11Z/)
REWIND 1
DO 80 M=1,NST
IF (M-1) 10,11,10
C READ MAP GRID DATA FOR DRAW SUBROUTINE
10 READ(1) X,Y
REWIND 1
C DRAW MAP GRID
11 CALL DRAW (386,X,Y,1,0,LA,IT,2.,2.,0,0,2,2,9,15,0,LAST)
C READ SHIP IDENTIFICATION NUMBER, DATE AND HOUR OF DEPARTURE, COORDINATES
C OF TRACK END POINTS, CONVERGENCE FACTOR, OPTION TO PLOT EARLIER
C TRACK, TIME STEP RECIPROCAL, AND NUMBER OF ITERATIONS
READ(50,14) GL,DATEX,FL,HR,XLG1,XLT1,XLG2,XLT2,RMUL,NN,NSTEP,LMAX,24
+ NP,PALF,PT
14 FORMAT (A4,2A8,F3.0,F6.1,F5.1,F6.1,F5.1,F3.0,I1,2I2,I1,F8.5,F6.3)
RSTEP = NSTEP
WRITE(51,15) LG,KATEX,LF,HR,KATE,XLG1,XLT1,XLG2,XLT2,RMUL,LMAX,
+ NSTEP,NN,NP
15 FORMAT(15HOROUTE OF SHIP A4,11H BEGINS ON A8,16H, JULIAN DATE = A429
+,1H,/1XF3.0,22H HOURS AFTER 1200Z ON A8/19H FROM LONGITUDE = F6.130
+,16H AND LATITUDE = F6.1/19H TO LONGITUDE = F6.1,16H AND LATITU31
+DE = F6.1//6H RMUL=F5.0,3X5HLMAX=I2,3X6HNSTEP=I2,3X3HNN=I1,3X3HNPN=I2
+I1//)

```

C	CHECK ON OPTION TO PLOT EARLIER TRACK	
	IF (NN) 16,19,16	33
16	READ(50,17) GL,PL,NK	34
17	FORMAT (2A8,I2)	35
	READ(50,29) (X(I),I=1,20), (Y(I),I=1,20)	36
29	FORMAT (10F5.2)	37
	CALL DRAW (NK,X,Y,2,2,LP,IT,2.,2.,0,0,2,2,9,15,0, LAST)	38
	WRITE(51,18) LG,LP	39
18	FORMAT(23H0EARLIER ROUTE OF SHIP A8,15H ON JULIAN DAY A4/66H HAS	40
	+BEEN PLOTTED USING PLUS SIGNS FOR SUCCESSIVE DAILY POSITIONS/)	41
C	COMPUTATION OF GEODESIC TRACK	
19	ARG = (XLG1-10.)/57.29577951	42
	COSLG1= COSF(ARG)	43
	SINLG1= SIN F(ARG)	44
	ARG = (XLG2-10.)/57.29577951	45
	COSLG2= COSF(ARG)	46
	SINLG2= SIN F(ARG)	47
	ARG = XLT1/57.29577951	48
	COSLT1= COSF(ARG)	49
	SINLT1= SIN F(ARG)	50
	ARG = XLT2/57.29577951	51
	COSLT2= COSF(ARG)	52
	SINLT2= SIN F(ARG)	53
	EL = SINLT2*COSLT1*SINLG1 - COSLT2*SINLT1*SINLG2	54
	EM = -SINLT2*COSLT1*COSLG1 + COSLT2*SINLT1*COSLG2	55
	EN = (SINLG2*COSLG1-COSLG2*SINLG1)*COSLT1*COSLT2	56
	ROOT = SQRTF(EL*EL + EM*EM + EN*EN)	57
	EL = EL/ROOT	58
	EM = EM/ROOT	59
	EN = EN/ROOT	60
	PR1= 31.205*COSLT1/(1.+SINLT1)	61
	X1 = PR1*COSLG1	62
	Y1 = PR1*SINLG1	63
	PR2= 31.205*COSLT2/(1.+SINLT2)	64
	X2 = PR2*COSLG2	65
	Y2 = PR2*SINLG2	66
	DELX = X2 - X1	67
	DELY = Y2 - Y1	68
	S12 = SQRTF(DELX*DELX + DELY*DELY)	69
	ARC= S12	70
	IF (XLG2-XLG1) 20,21,20	71
20	ARG= ABSF(EN/62.41)	72
	ARC= ASINF(ARG*S12)/ARG	73
21	COSA = -EN*Y1/31.205 + EM	74
	SINA = EN*X1/31.205 - EL	75
	IF (COSA) 23,22,23	76
22	ALF = SIGNF(1.5707963268,SINA)	77
	GO TO 27	78
23	ALF = ATANF(SINA/COSA)	79
	IF (COSA) 24,27,27	80

24	IF (SINA) 26,25,25	81
25	ALF = ALF + 3.1415926536	82
	GO TO 27	83
26	ALF = ALF - 3.1415926536	84
27	N3 = 0	85
	X(1) = X1 + 24.	86
	Y(1) = Y1 + 16.	87
	XFIN = X2 + 24.	88
	YFIN = Y2 + 16.	89
	LR = 0	90
	STEP = 1.0/RSTEP	91
	TAU = 0.0	92
	S = 0.0	93
	TVAR = HR/24.	94
	YVARS(5) = X(1)	95
	YVARS(6) = Y(1)	96
	YVARS(7) = 0.0	97
	N1 = 1	98
	N2 = 1	99
	DO 40 K=2,900	100
	DO 32 I=1,4	101
	TC = C(I)*STEP + TVAR	102
	DO 31 J=5,7	103
31	YC(J) = C(I)*AK(I-1,J) + YVARS(J)	104
	IF (ABSF(YC(5)-9.5)-7.5) 97,38,38	105
97	IF (ABSF(YC(6)-16.5)-14.5) 98,38,38	106
98	CALL TERP	107
	CALL AP3	108
	DELX = YC(5) - 24.	109
	DELY = YC(6) - 16.	110
	COSP = -DELY*EN/31.205 + EM	111
	SINP = DELX*EN/31.205 - EL	112
	COST = COSP*CK + SINP*SK	113
	A2MC2 = A*A - CC*CC	114
	SPMK = (SINP*CK - COSP*SK)/B	115
	SINTB = SPMK*SPMK*A2MC2	116
	V = A2MC2/(CC*COST + SQRTF(COST*COST+SINTB)*A)	117
	EMFI = (DELX*DELX + DELY*DELY + 973.75)/1043.638743	118
	CAPV = V*EMFI/8.5660416667	119
	DY(5) = CAPV*COSP	120
	DY(6) = CAPV*SINP	121
	DY(7) = CAPV	122
	DO 32 J=5,7	123
32	AK(I,J) = STEP*DY(J)	124
	DO 33 J=5,7	125
33	YVARS(J) = ( AK(1,J)+2.*AK(2,J)+2.*AK(3,J)+AK(4,J) )/6. + YVARS(J)	126
	TVAR = TVAR + STEP	127
	X(K) = YVARS(5)	128
	Y(K) = YVARS(6)	129
	N1 = K	130

	N2 = K	131
	IF (YVARS(7)-ARC) 35,34,34	132
34	RAT = (ARC-S)/(YVARS(7)-S)	133
	T = STEP*RAT + TAU	133.1
	X(K) = (X(K)-X(K-1))*RAT + X(K-1)	133.2
	Y(K) = (Y(K)-Y(K-1))*RAT + Y(K-1)	133.3
	N2 = K+1	134
	X(N2) = XFIN	135
	Y(N2) = YFIN	136
	GO TO 41	137
35	S = YVARS(7)	138
	TAU= TAU + STEP	139
	IF (K-900) 36,38,38	140
36	IF (ABS(X(K)-9.5)-7.5) 37,38,38	141
37	IF (ABS(Y(K)-16.5)-14.5) 40,38,38	142
38	T = TAU	143
	WRITE(51,39) LG	144
39	FORMAT(61HOMORE THAN 899 INTEGRATION STEPS OR WAVE DATA FIELD EXCE145	
	+EDED./21H OTS ROUTING OF SHIP A4,4X39HABANDONED BUT GEODESIC TRACK146	
	+ IS PLOTTED/)	147
	N3 = 1	148
	GO TO 41	149
40	CONTINUE	150
41	L = 0	151
	WRITE(51,42)	152
42	FORMAT(4X1HL4X2HN16X3HALF7X1HT7X5HX(N1)4X4HXFIN5X5HY(N1)4X4HYFIN/)	153
C	PRINT WEIGHTING FACTOR ALPHA AND TIME T OF GEODESIC TRACK	
	WRITE(51,43) L,N1,ALF,T,X(N1),XFIN,Y(N1),YFIN	154
43	FORMAT (I5,I6,F11.5,5F9.3)	155
C	ROTATE AND TRANSLATE AXES TO PLOT GEODESIC TRACK ON MAP GRID	
	DO 44 I=1,N2	156
	TEMP = .97780241408*X(I) - .20952908873*Y(I) + 3.0032502718	157
	Y(I) = .20952908873*X(I) + .97780241408*Y(I) - 4.4699538929	158
44	X(I) = TEMP	159
	CALL DRAW (N2,X,Y,N3+2,0,LG,IT,2.,2.,0,0,2,2,9,15,0, LAST)	160
	IF (N3) 80,45,80	161
C	PREPARE FOR LMAX ITERATIONS TOWARD MINIMAL-TIME TRACK	
45	TC = HR/24.	162
	X(1) = X1 + 24.	163
	Y(1) = Y1 + 16.	164
	YC(5) = X(1)	165
	YC(6) = Y(1)	166
	CALL TERP	167
	DO 9 I=2,399	168
	X(I) = 0.0	169
9	Y(I) = 0.0	170
	X(101) = H	171
	YVARS(5) = X(1)	172
	YVARS(6) = Y(1)	173
	CALL ANGLE	174

	Y(101) = XK	175
	X(201) = XLG1	176
	Y(201) = XLT1	177
	LR = 1	178
	IF (NP) 81,82,81	178.1
81	ALF = PALF	178.2
	T = PT	178.3
	COSA = COSF(ALF)	178.4
	SINA = SINF(ALF)	178.5
82	DO 69 L=1,LMAX	179
	TVAR = HR/24.	180
	TAU = 0.0	181
	N1 = XINTF(RSTEP * T)	182
	XN1 = N1	183
	STEP1 = 1.0/RSTEP	184
	FSTEP = -XN1/RSTEP + T	185
	N1 = N1 + 2	186
	DO 46 I=1,8	187
46	YVARS(I) = 0.0	188
	YVARS(1) = 1.0	189
	YVARS(4) = 1.0	190
	YVARS(5) = X(1)	191
	YVARS(6) = Y(1)	192
	YVARS(7) = 1.0	192.1
	NK = 1	193
	DO 66 K=2,N1	194
	STEP = STEP1	195
	IF (K-N1) 48,47,48	196
47	STEP = FSTEP	197
48	DO 52 I=1,4	198
	TC = C(I)*STEP + TVAR	199
	DO 49 J=1,8	200
49	YC(J) = C(I)*AK(I-1,J) + YVARS(J)	201
	IF (ABSF(YC(5)-9.5)-7.5) 99,65,65	202
99	IF (ABSF(YC(6)-16.5)-14.5) 100,65,65	203
100	XLAM = YC(1)*COSA + YC(3)*SINA	204
	XMU = YC(2)*COSA + YC(4)*SINA	205
	CLAM = SQRTF(XLAM*XLAM + XMU*XMU)	206
	CALL TERP	207
	CALL AP3	208
	DKX = CK*SKX - SK*CKX	209
	DKY = CK*SKY - SK*CKY	210
	ABS = (XLAM*CK + XMU*SK)*A/CLAM	211
	ORD = (XMU*CK - XLAM*SK)*B/CLAM	212
	HYP = SQRTF(ABS*ABS + ORD*ORD)	213
	SINB= ORD/HYP	214
	COSB= ABS/HYP	215
	VMAJ= A * COSB - CC	216
	VMIN= B * SINB	217

V = SQRTF(VMAJ*VMAJ + VMIN*VMIN)	218
COSP= (CK*VMAJ - SK*VMIN)/V	219
SINP= (SK*VMAJ + CK*VMIN)/V	220
COST= VMAJ/V	221
VBR= V/8.5660416667	222
DELX = YC(5) - 24.	223
DELY= YC(6) - 16.	224
EMFI = (DELX*DELX + DELY*DELY + 973.75)/1043.638743	225
CAPV = VBR * EMFI	226
DY(5)= CAPV * COSP	227
DY(6)= CAPV * SINP	228
EMFIX= DELX/521.8193715	229
EMFIY= DELY/521.8193715	230
B2MA2= B*B - A*A	231
AMCCB= -CC*COSB + A	232
ACPDCB = A*CC + B2MA2*COSB	232.1
RAT = (ACPDCB*SINB/B)/AMCCB	233
VP = RAT * V	234
CAPVP= RAT * CAPV	235
QUO = V/AMCCB	236
DIV = 1.0	237
IF (RAT) 12,13,12	238
DIV = RAT*RAT + (B2MA2*SINB*SINB/B - VP*COST/SINB)*QUO*QUO/B + 1.	239
DET = YC(1)*YC(4) - YC(2)*YC(3)	240
QUO = SQRTF(RAT*RAT + 1.0)/CLAM	241
FORCE= CAPV*DET*DET*QUO*QUO*QUO/DIV	242
FNUM = -RAT * AMCCB	243
DBDH = (DA*COSB - DC)*COSB + A*DB*SINB*SINB/B	244
RATX = (FNUM*DKX + HX*DBDH)/AMCCB	245
RATY = (FNUM*DKY + HY*DBDH)/AMCCB	246
CAPVX= (RATX*EMFI + EMFIX)*VBR	247
CAPVY= (RATY*EMFI + EMFIY)*VBR	248
F1=(((A+AMCCB)*B2MA2*COSB+A*A*CC)*COSB-(CC*CC+B2MA2)*A)/AMCCB)/	248.01
+ AMCCB)/B	248.02
F2 = ((DA/A-DB/B)*COSB - DC/A)*SINB*F1	248.03
F3 = (CC*SINB*F1/A)/CAPV	248.04
F4 = ((ACPDCB*COSB - B*B)*F1/A)/B	248.05
F5 = (((B*DB-A*DA)*2.*COSB+CC*DA+A*DC)/ACPDCB-DB/B+(DC*COSB-DA)/	248.06
+ AMCCB)*RAT	248.07
QUOX = (F2+F5)*HX + F3*CAPVX + F4*DKX	248.08
QUOY = (F2+F5)*HY + F3*CAPVY + F4*DKY	248.09
CAPVPX = CAPVX*RAT + CAPV*QUOX	248.10
CAPVPY = CAPVY*RAT + CAPV*QUOY	248.11
F6 = (-RAT*CAPVX + CAPVPX)*QUO/DIV	248.12
F7 = (-RAT*CAPVY + CAPVPY)*QUO/DIV	248.13
F8 = F7*XLAM - F6*XMU	248.14
DY(7) = F8*YC(7)	248.15
DY(8) = FORCE/YC(7)	248.16

SUM = YC(1)*COSP + YC(2)*SINP	249
DY(1) = -CAPVX * SUM	250
DY(2) = -CAPVY * SUM	251
SUM = YC(3)*COSP + YC(4)*SINP	252
DY(3) = -CAPVX * SUM	253
DY(4) = -CAPVY * SUM	254
DO 52 J=1,8	255
52 AK(I,J) = STEP * DY(J)	256
DO 53 J=1,8	257
53 YVARS(J) = ( AK(1,J)+2.*AK(2,J)+2.*AK(3,J)+AK(4,J) )/6. + YVARS(J)	258
* TVAR = TVAR + STEP	259
TAU = TAU + STEP	260
IF (N1-K) 54,56,54	261
54 IF (LMAX-L) 62,55,62	262
55 IF ((K-1)/NSTEP+1-NK) 62,62,56	263
56 NK = NK + 1	264
XLAM = YVARS(1)*COSA + YVARS(3)*SINA	265
XMU = YVARS(2)*COSA + YVARS(4)*SINA	266
CLAM = SQRTF(XLAM*XLAM + XMU*XMU)	267
YC(5) = YVARS(5)	268
YC(6) = YVARS(6)	269
LR = 0	270
CALL TERP	271
CALL AP3	272
LR = 1	273
ABS = (XLAM*CK + XMU*SK)*A/CLAM	274
ORD = (XMU*CK - XLAM*SK)*B/CLAM	275
HYP = SQRTF(ABS*ABS + ORD*ORD)	276
VMAJ = A * ABS/HYP - CC	277
VMIN = B * ORD/HYP	278
V = SQRTF(VMAJ*VMAJ + VMIN*VMIN)	279
COSP = (CK*VMAJ - SK*VMIN)/V	280
SINP = (SK*VMAJ + CK*VMIN)/V	281
DET = YVARS(1)*YVARS(4) - YVARS(3)*YVARS(2)	282
CONA = -XMU*YVARS(7)*YVARS(8)/DET	282.
CONB = XLAM*YVARS(7)*YVARS(8)/DET	282.
IF (LMAX-L) 61,60,61	283
60 X(NK) = YVARS(5)	284
Y(NK) = YVARS(6)	285
X(NK+100) = H	286
X(NK+300) = TAU	287
CALL ANGLE	288

Y(NK+100) = XK	289
X(NK+200) = XLG	290
Y(NK+200) = XLT	291
61 IF (N1-K) 62,67,62	292
62 DELX = YVARS(5) - X(1)	293
DELY = YVARS(6) - Y(1)	294
IF (DELX*DELX + DELY*DELY - S12*S12) 63,65,65	295
63 IF (ABSF(YVARS(5)- 9.5)- 7.5) 64,65,65	296
64 IF (ABSF(YVARS(6)-16.5)-14.5) 66,65,65	297
65 N1 = K	298
T = TAU	299
GO TO 56	300
66 CONTINUE	301
PRINT ALPHA, T, X, AND Y AT END OF EACH ITERATION	
67 WRITE(51,43) L,N1,ALF,T,YVARS(5),XFIN,YVARS(6),YFIN	302
DELX = YVARS(5) - 24.	303
DELY = YVARS(6) - 16.	304
EMFI = (DELX*DELX + DELY*DELY + 973.75)/1043.638743	305
DIFX = XFIN - YVARS(5)	306
DIFY = YFIN - YVARS(6)	307
CAPV = V * EMFI/8.5660416667	308
XDOT = CAPV * COSP	309
YDOT = CAPV * SINP	310
DETER= XDOT*CONB - YDOT*CONA	311
DIFT = (CONB*DIFX - CONA*DIFY)/DETER	312
DIFA = (XDOT*DIFY - YDOT*DIFX)/DETER	313
T = DIFT + T	314
ALF = DIFA/RMUL + ALF	315
COSA = COSF(ALF)	316
SINA = SINF(ALF)	317
PRINT NEW VALUES OF ALPHA AND T	
WRITE(51,50) ALF,T	318
50 FORMAT (11XF11.5,F9.3)	318.1
69 CONTINUE	319
IF (DIFX*DIFX + DIFY*DIFY - EMFI*EMFI*.2366) 72,72,70	320
70 WRITE(51,71) LG	321
71 FORMAT(20H0 OTS ROUTE OF SHIP A4,47H MORE THAN 100 MILES FROM DEST	322
+INATION BUT TRACK/69H IS PLOTTED. INCREASE RMUL OR LMAX, OR BOTH,	323
+ TO IMPROVE CONVERGENCE.)	324
TABULATE FINAL TRACK DAILY POSITION, WAVE HEIGHT AND DIRECTION	
72 WRITE(51,73)	325
73 FORMAT (1H0/4X4HDAYS7X5HLONGI4X5HLATI-5X4HWAVE5X14HWAVE DIRECTION/	326
+2X9HOF TRAVEL4X5H-TUDE4X4HTUDE5X6HHEIGHT6X10HFROM NORTH/)	327
WRITE(51,74)(X(K+300),X(K+200),Y(K+200),X(K+100),Y(K+100),K=1,NK)	328
74 FORMAT (F9.2,F11.1,F8.1,F9.0,F14.0)	329
ROTATE AND TRANSLATE AXES FOR PLOT OF DAILY POSITIONS	
DO 75 I=1,NK	330
TEMP = .97780241408*X(I) - .20952908873*Y(I) + 3.0032502718	331
Y(I) = .20952908873*X(I) + .97780241408*Y(I) - 4.4699538929	332
75 X(I) = TEMP	333

C	PUNCH 11 CARDS USEABLE FOR A LATER PLOT OF TRACK	
	WRITE(52,76) LG,LF,NK	334
76	FORMAT (2A8,I2,6I1H )	335
	WRITE(52,78) (((RX(I,J),I=1,10),LG,LF,J),J=1,2),	336
+	((RY(I,J),I=1,10),LF,LG,J),J=1,2)	337
78	FORMAT (10F5.2,2A8,I2,11X1H )	338
	CALL DRAW (NK,X,Y,3,4,LF,IT,2.,2.,0,0,2,2,9,15,0,LAST)	339
	WRITE(51,93)	340
93	FORMAT (1H1)	341
C	PROCEED TO COMPUTE THE ROUTE OF NEXT SHIP	
80	CONTINUE	342
	STOP	343
	END	344
	SUBROUTINE TERP	345
	DIMENSION MHD(4608),YC(8),HT(4,4),CT(4,4),ST(4,4),YVARS(8),P(4),	346
+	Q(4),PX(4),QY(4),HD(4),CD(4),SD(4),HS(4),CS(4),SS(4),HP(4),CP(4),	347
+	SP(4),HPX(4),HPY(4),CPX(4),CPY(4),SPX(4),SPY(4),C(4),XHD(4608)	348
	COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,	349
+	A,B,CC,DA,DB,DC,LR	350
	EQUIVALENCE (MHD,XHD),(ID,ARG)	351
	MASK= 77777777B	352
	DTC = 2.*TC	353
	L = XINTF(DTC)	354
	IF (L-3) 1,1,7	355
1	TT = (-INTF(DTC)+DTC)*2. - 1.	356
	TP1= TT + 1.	357
	TM1= TT - 1.	358
	T2M= TP1*TM1	359
	IF (L) 2,2,3	360
2	K4 = 3	361
	TM3= TT - 3.	362
	C(1)= TM1*TM3/8.	363
	C(2)=-TP1*TM3/4.	364
	C(3)= T2M/8.	365
	GO TO 16	366
3	K4 = 4	367
	IF (L-2) 4,4,6	368
4	G = (3.*TT+2.)*TT - 9.	369
	F = -4.*TT + G	370
	C(1)= -T2M*TM1/16.	371
	C(2)= G*TM1/16.	372
5	C(3)= -F*TP1/16.	373
	C(4)= T2M*TP1/16.	374
	GO TO 15	375
6	C(1)= -T2M*TM1/16.	376
	C(2)=((2.*TT+1.)*TT-7.)*TM1/12.	377
	C(3)=((1.-TT)*TT+4.)*TP1/8.	378
	C(4)= T2M*TP1/48.	379
	GO TO 15	380
7	L = XINTF(TC-2.) + 4	381

IF (L-8) 9,8,8	382
8 K4 = 1	383
L = 7	384
C(1)= 1.	385
GO TO 16	386
9 TT = (-INTF(TC)+TC)*2. - 1.	387
TP1= TT + 1.	388
TM1= TT - 1.	389
T2M= TP1*TM1	390
G = (3.*TT+2.)*TT - 9.	391
F = -4.*TT + G	392
C(1)= -T2M*TM1/16.	393
IF (L-7) 11,10,8	394
10 K4 = 2	395
C(2)= (G*TM1 + (T2M-F)*TP1)/16.	396
GO TO 15	397
11 C(2)= G*TM1/16.	398
IF (L-6) 13,12,10	399
12 K4 = 3	400
C(3)= (T2M-F)*TP1/16.	401
GO TO 15	402
13 K4 = 4	403
IF (L-5) 14,5,12	404
14 C(1)= -T2M*TM1/6.	405
C(2)=((5.*TT+2.)*TT-11.)*TM1/16.	406
C(3)=((-5.*TT+4.)*TT+13.)*TP1/24.	407
C(4)= T2M*TP1/16.	408
15 L = L-1	409
16 M = XINTF(YC(5)) - 2	410
N = XINTF(YC(6)) - 2	411
XX = (-INTF(YC(5))+YC(5))*2.0 - 1.0	412
YY = (-INTF(YC(6))+YC(6))*2.0 - 1.0	413
XP1= XX + 1.0	414
XM1= XX - 1.0	415
YP1= YY + 1.0	416
YM1= YY - 1.0	417
X2M= XP1*XM1	418
Y2M= YP1*YM1	419
P(1) = -XM1*X2M/16.	420
P(2) = ((3.*XX+2.)*XX-9.)*XM1/16.	421
P(3) = (-XX*XX+9.)/8. - P(2)	422
P(4) = XP1*X2M/16.	423
Q(1) = -YM1*Y2M/16.	424
Q(2) = ((3.*YY+2.)*YY-9.)*YM1/16.	425
Q(3) = (-YY*YY+9.)/8. - Q(2)	426
Q(4) = YP1*Y2M/16.	427
IF (LR) 17,18,17	428
17 PX(4)= (3.*XX-1.)*XP1/8.	429
PX(1)= XX/2. - PX(4)	430
PX(2)= (9.*XX-11.)*XP1/8.	431

PX(3)= -XX/2. - PX(2)	432
QY(4)= (3.*YY-1.)*YP1/8.	433
QY(1)= YY/2. - QY(4)	434
QY(2)= (9.*YY-11.)*YP1/8.	435
QY(3)= -YY/2. - QY(2)	436
18 DO 27 K=1,K4	437
HP(K) = 0.0	438
CP(K) = 0.0	439
SP(K) = 0.0	440
IF (LR) 19,20,19	441
19 HPX(K)= 0.0	442
HPY(K)= 0.0	443
CPX(K)= 0.0	444
CPY(K)= 0.0	445
SPX(K)= 0.0	446
SPY(K)= 0.0	447
20 KK = ((K+L)*32+N)*18 + M - 594	448
DO 23 J=1,4	449
HD(J) = 0.0	450
CD(J) = 0.0	451
SD(J) = 0.0	452
IF (LR) 21,22,21	453
21 HS(J) = 0.0	454
CS(J) = 0.0	455
SS(J) = 0.0	456
22 JJ = 18*J + KK	457
DO 23 I=1,4	458
II = I + JJ	459
HT(I,J) = XHD(II)	460
ID = MHD(II) .AND. MASK	461
ID = ID * 16777216	462
CT(I,J) = COSF(ARG)	463
23 ST(I,J) = SINF(ARG)	464
DO 25 I=1,4	465
DO 25 J=1,4	466
HD(I) = Q(J)*HT(I,J) + HD(I)	467
CD(I) = Q(J)*CT(I,J) + CD(I)	468
SD(I) = Q(J)*ST(I,J) + SD(I)	469
IF (LR) 24,25,24	470
24 HS(I) = P(J)*HT(J,I) + HS(I)	471
CS(I) = P(J)*CT(J,I) + CS(I)	472
SS(I) = P(J)*ST(J,I) + SS(I)	473
25 CONTINUE	474
DO 27 I=1,4	475
HP(K) = HD(I)*P(I) + HP(K)	476
CP(K) = CD(I)*P(I) + CP(K)	477
SP(K) = SD(I)*P(I) + SP(K)	478
IF (LR) 26,27,26	479
26 HPX(K)=HD(I)*PX(I) + HPX(K)	480
CPX(K)=CD(I)*PX(I) + CPX(K)	481

SPX(K)=SD(I)*PX(I) + SPX(K)	482
HPY(K)=HS(I)*QY(I) + HPY(K)	483
CPY(K)=CS(I)*QY(I) + CPY(K)	484
SPY(K)=SS(I)*QY(I) + SPY(K)	485
27 CONTINUE	486
H = 0.0	487
CK = 0.0	488
SK = 0.0	489
IF (LR) 28,29,28	490
28 HX = 0.0	491
HY = 0.0	492
CKX = 0.0	493
CKY = 0.0	494
SKX = 0.0	495
SKY = 0.0	496
29 DO 31 K=1,K4	497
H = C(K)*HP(K) + H	498
CK = C(K)*CP(K) + CK	499
SK = C(K)*SP(K) + SK	500
IF (LR) 30,31,30	501
30 HX = C(K)*HPX(K) + HX	502
HY = C(K)*HPY(K) + HY	503
CKX = C(K)*CPX(K) + CKX	504
CKY = C(K)*CPY(K) + CKY	505
SKX = C(K)*SPX(K) + SKX	506
SKY = C(K)*SPY(K) + SKY	507
31 CONTINUE	508
RAD = SQRTF(CK*CK + SK*SK)	509
CK = CK/RAD	510
SK = SK/RAD	511
RETURN	512
END	513
SUBROUTINE ANGLE	514
DIMENSION MHD(4608),YC(8),YVARS(8)	515
COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,	516
+ A,B,CC,DA,DB,DC,LR	517
DELX = YVARS(5) - 24.	518
DELY = YVARS(6) - 16.	519
COSXK= -DELX*CK - DELY*SK	520
SINXK= DELX*SK - DELY*CK	521
IF (COSXK) 2,1,2	522
1 XK = SIGNF(90.,SINXK)	523
GO TO 6	524
2 XK = ATANF(SINXK/COSXK)*57.29577951	525
IF (COSXK) 3,6,6	526
3 IF (SINXK) 5,4,4	527
4 XK = XK + 180.	528
GO TO 6	529
5 XK = XK - 180.	530
6 IF (XK) 7,8,8	531

7	XK = 360. + XK	532
8	XT = DELX*.98480775 - DELY*.17364818	533
	YT = DELX*.17364818 + DELY*.98480775	534
	RAD= SQRTF(XT*XT + YT*YT)	535
	IF (XT) 10,9,10	536
9	XLG = SIGNF(90.0,YT)	537
	GO TO 14	538
10	XLG = ATANF(YT/XT)*57.29577951	539
	IF (XT) 11,14,14	540
11	IF (YT) 13,12,12	541
12	XLG = XLG + 180.	542
	GO TO 14	543
13	XLG = XLG - 180.	544
14	XLT = -ATANF(RAD/31.205)*114.591559 + 90.0	545
	RETURN	546
	END	547
	SUBROUTINE AP3	548
	DIMENSION MHD(4608),YC(8),YVARS(8)	549
	COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,	550
+	A,B,CC,DA,DB,DC,LR	551
	R1 = SQRTF((.062760850324*H-.60018313990)*H+4.7014047597)	552
	VF = 0.021541997619*H + 19.278272298 - R1	553
	R2 = SQRTF((.060104035000*H-.96636105838)*H+6.1294779871)	554
	B = -0.12663045716*H + 19.585778258 - R2	555
	IF (H-17.) 1,1,2	556
1	R3 =SQRTF((.083601632403*H-1.3340008783)*H+7.1705253492)	557
	VH = -0.24791650490*H + 19.793624009 - R3	558
	GO TO 3	559
2	R4 =SQRTF((.055777533214*H-3.0851911409)*H+45.698170763)	560
	VH = -0.31013284648*H + 14.848653764 + R4	561
3	A = (VF+VH)*.5	562
	CC = A-VH	563
	IF (LR) 4,8,4	564
4	DVF= (-.062760850324*H+.30009156995)/R1 +0.021541997619	565
	DB = (-.060104035000*H+.48318052919)/R2 - 0.12663045716	566
	IF (H-17.) 5,5,6	567
5	DVH=(-.083601632403*H+.66700043915)/R3-0.24791650490	568
	GO TO 7	569
6	DVH= (.055777533214*H-1.54259557045)/R4-0.31013284648	570
7	DA =(DVF+DVH)*.5	571
	DC =DA-DVH	572
8	RETURN	573
	END	574
	END	575
	FINIS	576

EXECUTE.

OB 0574

BLEICK

BOX 6

C2AP3

DECEMBER 6

1966

JUL26,66

1

666JUL26,66J207 00.-122.5 37.9 139.6 35.6 10024 7

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SUBROUTINE AP2
  DIMENSION MHD(4608),YC(8),YVARS(8)
  COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,
+      A,B,CC,DA,DB,DC,LR
  R1 = SQRTF((.041783709356*H-.42321401072)*H+2.2342337579)
  VF = -.028281950577*H + 17.494735347 - R1
  R2 = SQRTF((.058458667266*H-.90729449065)*H+6.4033842487)
  B = -0.14520001518*H + 18.530490911 - R2
  IF (H-15.) 1,1,2
1  R3 =SQRTF((.23341292994*H-3.1096617758)*H+29.275404601)
  VH = -0.25152614353*H + 21.408836894 - R3
  GO TO 3
2  R4 =SQRTF((.14668786198*H-6.8828319323)*H+105.12448592)
  VH = -0.36970234218*H + 11.346369501 + R4
3  A = (VF+VH)*.5
  CC = A-VH
  IF (LR) 4,8,4
4  DVF= (-.041783709356*H+.21160700536)/R1 - .028281950577
  DB = (-.058458667266*H+.45364724533)/R2 - 0.14520001518
  IF (H-15.) 5,5,6
5  DVH= (-.23341292994*H+1.5548308879)/R3-0.25152614353
  GO TO 7
6  DVH= (.14668786198*H-3.44141596615)/R4-0.36970234218
7  DA =(DVF+DVH)*.5
  DC =DA-DVH
8  RETURN
  END

```

-COOP,BOX 6,BLEICK,I/1/O/2/S/56/57,3,10000,0, TAPE - 6 DEC 66.

-FTN,L,A,E.

PROGRAM TAPE	0
DIMENSION X(900),Y(900),MD(63,63),ND(3969),MHD(18,32,8)	1
EQUIVALENCE (MD,ND),(ID,ARG),(TEMP,ITEM),(IH,H)	2
REWIND 1	3
REWIND 2	4
ISCALE = 200000000000000000B	5
MASK = 777777770000000000B	6
C READ COORDINATES FOR MAP GRID OF DRAW SUBROUTINE	
READ(50,1) (X(I),I=1,390), (Y(I),I=1,390)	7
1 FORMAT (15F5.3)	8
WRITE(2) X,Y	9
IF (IOCHECK,2) 2,4	10
2 WRITE(51,3)	11
3 FORMAT (37H0 PARITY ERROR OCCURRED ON X,Y WRITE/)	12
4 DO 43 K=1,8	13
C READ WAVE DIRECTION FROM FLEET NUMERICAL WEATHER FACILITY TAPE	
BUFFER IN(1,2) (ND(1),ND(3969))	14
5 IF(UNIT,1) 6,14,8,10	15
6 GO TO 5	16
8 WRITE(51,9) K	17

9	FORMAT (44H0 DIRECTION EOF OR EOT ERROR OCCURRED ON K=I1/)	18
	STOP	19
10	WRITE(51,11) K	20
11	FORMAT (49H0 DIRECTION PARITY OR LENGTH ERROR OCCURRED ON K=I1/)	21
	M = LENGTHF(1)	22
	IF (M-3969) 12,14,12	23
12	WRITE(51,13) M	24
13	FORMAT (28H0 DIRECTION BUFFER LENGTH =I5/)	25
C	COMPUTE WAVE DIRECTION K FROM X AXIS OF STEREOGRAPHIC GRID	
14	DO 42 I=1,18	26
	DELX = I-24	27
	DO 42 J=1,32	28
	DELY = J-16	29
	ID = MD(I+8,J+16)/2048 + ISCALE	30
	ARG = (ARG + 0.0)*11.17010721	31
	COS = COSF(ARG)	32
	SIN = SINF(ARG)	33
	ABS = -DELX*COS - DELY*SIN	34
	ORD = DELX*SIN - DELY*COS	35
	IF (ABS) 36,35,36	36
35	TEMP = SIGNF(1.5707963268,ORD)	37
	GO TO 40	38
36	TEMP = ATANF(ORD/ABS)	39
	IF (ABS) 37,40,40	40
37	IF (ORD) 39,38,38	41
38	TEMP = TEMP + 3.1415926536	42
	GO TO 40	43
39	TEMP = TEMP - 3.1415926536	44
40	IF (TEMP) 41,42,42	45
41	TEMP = TEMP + 6.2831853072	46
C	SHIFT FLOATING-POINT K TO LOWER HALF OF MHD MATRIX WORD	
42	MHD(I,J,K) = ITEM/16777216	47
C	READ WAVE PERIOD FROM FLEET NUMERICAL WEATHER FACILITY TAPE (NOT USED)	
	BUFFER IN(1,2) (ND(1),ND(3969))	48
15	IF(UNIT,1) 16,24,18,20	49
16	GO TO 15	50
18	WRITE(51,19) K	51
19	FORMAT (41H0 PERIOD EOF OR EOT ERROR OCCURRED ON K=I1/)	52
	STOP	53
20	WRITE(51,21) K	54
21	FORMAT (46H0 PERIOD PARITY OR LENGTH ERROR OCCURRED ON K=I1/)	55
	M = LENGTHF(1)	56
	IF (M-3969) 22,24,22	57
22	WRITE(51,23) M	58
23	FORMAT (25H0 PERIOD BUFFER LENGTH =I5/)	59
C	READ WAVE HEIGHT H FROM FLEET NUMERICAL WEATHER FACILITY TAPE	
24	BUFFER IN(1,2) (ND(1),ND(3969))	60
25	IF(UNIT,1) 26,34,28,30	61
26	GO TO 25	62
28	WRITE(51,29) K	63

29	FORMAT (41H0 HEIGHT EOF OR EOT ERROR OCCURRED ON K=11/)	64
	STOP	65
30	WRITE(51,31) K	66
31	FORMAT (46H0 HEIGHT PARITY OR LENGTH ERROR OCCURRED ON K=11/)	67
	M = LENGTHF(1)	68
	IF (M-3969) 32,34,32	69
32	WRITE(51,33) M	70
33	FORMAT (25H0 HEIGHT BUFFER LENGTH = 15/)	71
PACK FLOATING-POINT H AND K IN MHD MATRIX		
34	DO 43 I=1,18	72
	DO 43 J=1,32	73
	IH = MD(I+8,J+16)/2048 + ISCALE	74
	H = (H + 0.0)*64.	75
	IH = IH .AND. MASK	76
43	MHD(I,J,K) = MHD(I,J,K) + IH	77
	REWIND 1	78
	WRITE(2) MHD	79
	IF(IOCHECK,2) 44,46	80
44	WRITE(51,45)	81
45	FORMAT (37H0 PARITY ERROR OCCURRED ON MHD WRITE/)	82
46	END FILE 2	83
	REWIND 2	84
PRINT PART OF MHD MATRIX TO CHECK PACKING OF DATA		
	WRITE(51,47) (((MHD(I,J,K),I=1,7),J=1,32,31),K=1,8)	85
47	FORMAT (7017/)	86
	STOP	87
	END	88
	END	89
	FINIS	90

EXECUTE.

978	9781746117461	978	978	2070	4931	4133	3388	2698	2065	1491	978	978ABS	1		
491	2064	2697	5198	4550	3956	3418	2937	2515	2152	1851	1612	1435	1321	1271ABS	2
284	1361	1501	1704	1969	2296	2684	3130	3635	4197	4814	5484	6205	6976	7794ABS	3
764	9841	8966	8144	7378	6669	6021	5437	4917	4465	4082	3769	3528	3359	3262ABS	4
240	3290	3414	3611	3879	4219	4628	5106	5651	6259	6931	7661	10146	9307	8535ABS	5
834	7207	6658	6188	5800	5496	5278	5146	5102	5145	5275	5491	5793	6179	6647ABS	6
196	7821	8520	9291	10128	11028	11987	13000	14062	17461	17461	16477	15523	14600	13714ABS	7
868	12067	11312	10608	9957	9363	8827	8353	7942	7596	7316	7104	6960	6885	6880ABS	8
944	7078	7280	7550	7886	8288	8753	9279	9865	10507	11204	11951	12746	15672	14829ABS	9
025	13265	12551	11887	11277	10723	10227	9793	9422	9116	8877	8705	8601	8567	8601ABS	10
705	8877	9116	9422	9793	10227	10723	11277	11887	12551	13265	14026	14829	15673	16551ABS	11
461	17461	16663	15897	15167	14475	13825	13220	12664	12159	11708	11311	11097	10694	10475ABS	12
318	10224	10193	10224	10318	10475	10694	10973	11311	11708	12159	12664	13220	13825	14475ABS	13
167	15897	16663	17461	17461	16827	16221	15645	15100	14590	14117	13682	13288	12936	12628ABS	14
361	12149	11979	11858	11785	11760	11785	11858	11979	12149	12366	12628	12936	13288	13682ABS	15
171	14590	15100	15645	16221	16827	17461	17461	16989	16539	16113	15712	15388	14991	14674ABS	16
871	14131	13908	13717	13560	13438	13350	13297	13279	13297	13350	13438	13560	13717	13908ABS	17
311	14387	14674	14991	15338	15712	16113	16539	16989	17461	17461	17150	16855	16577	16317ABS	18
741	15851	15647	15462	15299	15156	15035	14935	14857	14801	14768	14757	14768	14801	14857ABS	19
351	5035	15156	15299	15462	15647	15851	16074	16317	16577	16855	17150	17461	17461	17312ABS	20

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171721704116919168061670216608165231644816382163271628116246162201620516200ABS1
162051622016246162811632716382164481652316608167021680616919170411717217312ABS2
17461174611672215277174611746113665118241746117461 9667 70621746117461 3797ABS3
 978 9781746117461 978 9781746117461 978 9781746117461 978 9781746117461ABS4
17461 978 9781746117461 978 9781746117461 978 9781746117461 2520 5878ABS5
1746117461 86421099117461174611304014870174611746116537 ABS6
 6292870528705 629 629 2224 629 629 1612 2637 3700 4797 5927 708525322ORD
264802760928705287052772126703256552457823478223572121720063188981772516547ORD
1536814192130221186110713 9580 8467 7377 6312 5275 4271 3302 2369 1478 629ORD3
 629 1408 2242 3127 4061 5039 6059 7116 8207 93281047311640128241402015224ORD4
164321763918841200332121122371235072461725695267392774328705287052777226783ORD5
2574224655235282236421171199531871817470162161496213714124781126110067 8903ORD6
 7774 6686 5645 4654 3720 2846 2037 1297 629 629 976 1379 1844 2372 2958ORD7
 3601 4298 5046 5842 6682 7562 8480 943110410114151244013481145331559316656ORD8
177161877019813208412184922832237882471025597264432724628001287052870528163ORD9
275642691126207254562466023825229532205021118201641919018203172051620315202ORD0
1420413217122431128810357 9453 8582 7746 6951 6200 5496 4843 4244 3702 3219ORD1
 2797 4582 5005 5483 6013 6593 7220 7890 8602 93501013210943117801263813514ORD2
144031530116204171061800418893197692062721464222762305723806245172518725814ORD3
263942692427402278252605225660252272475624248237052313022525218932123720559ORD4
1986219149184241768916948162041545914718139831325812545118491117010514 9882ORD5
 9277 8702 8159 7651 7180 6747 6355 8154 8507 8887 9294 9726101811065711154ORD6
116681219912744133011386914445150281561516204167921737917962185381910619663ORD7
202082073921254217502222622681231132352023900242532236022060217432141221067ORD8
207092033819957195661916618757183421792117496170671663616204157711534014911ORD9
144861406513650132421284112450120691169811340109951066410347100471222212442ORD0
126671289713133133721361613864141151437014627148861514715410156741593816204ORD1
164691673316997172601752117781180381829218543187911903519275195101974019966ORD2
201852726128705287052522423685287052870522466214622870528705206081986428705ORD3
287052792919200185942555823357180311750021277192781698916491173271539415997ORD4
1549913448114591499114464 9395 72161390713309 4876 23181265511926 629 629ORD5
1109310117 629 629 8938 7461 629 629 5521 2814 629 ORD6

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List of cards in programs TAPE, VC2AP3 and AP2 requiring changes if the geometric dimensions and/or origin of the MHD array are changed:

TAPE: 1, 26, 27, 28, 29, 30, 72, 73, 74 and perhaps 85, and the 52 input BCD data cards for the computer plotting of the map grid.

VC2AP3: 1, 86, 87, 88, 89, 105, 106, 109, 110, 141, 142, 157, 158, 163, 164, 202, 203, 223, 224, 296, 297, 303, 304, 331, 332, 346, 348, 448, 457, 515, 518, 519 and 549.

AP2: DIMENSION statement.

A. IDENTIFICATION:

TITLE: General Graph Output Subroutine  
CO-OP ID: J7-NPS-DRAW (FORTRAN 60)  
CATEGORY: Output for Off-Line Plotting  
PROGRAMMER: J. R. Ward  
DATE: February 1964;  
REVISED: June 1965

B. PURPOSE:

This subroutine, when provided with the necessary information, generates a magnetic tape in the proper format for subsequent off-line graph plotting using the CDC 160 or 160A GRAFPLLOT program and a CalComp 165 Plotter (see references 1 and 2). Provision is made for curve drawing and point plotting, automatic scaling, graph titling and axis annotating. An attempt was made to provide a considerable amount of flexibility, at the expense, necessarily, of a relatively large number of arguments and a rather high memory requirement.

C. USAGE:

1. Definitions:

In what follows the word "graph" will be taken to mean one piece or frame of graph paper on which there may be plotted one or more curves and/or sets of points. A "curve" will mean a continuous line generated by the sequence of straight lines joining successive points of the set defining the curve. A "point plot" will describe the representation of a succession of points by means of symbols (such as a cross) on the graph. The points are not connected in a point plot.

2. Calling Arguments:

All necessary information is transferred to DRAW through the calling arguments. The call statement is: CALL DRAW (NUMPTS, X,Y,MODCURV,ITYPE,LABEL,ITITLE,EXSCALE,YSCALE,IXUP,IYRIGHT,MODEXAX,MODEYAX,IWIDE,IHIGH,IGRID,LAST)

It is important to realize that one and only one curve or set of points is plotted each time DRAW is called. However, it is possible to call DRAW repeatedly if several curves and/or sets of points are wanted on one graph.

The calling arguments are as follows:

- a. NUMPTS: The number of points defining a curve ( $2 \leq \text{NUMPTS} \leq 900$ ), or the number of points to be point plotted ( $2 \leq \text{NUMPTS} \leq 30$ ).
- b. X: The array of X-ordinates ( $|X_i| \leq 10^{99}$  for  $i=1,2,\dots,\text{NUMPTS}$ ). X must be dimensioned at least equal to NUMPTS in the calling program.

All points will be considered to have the same X-ordinate if  $|X_{\max} - X_{\min}| \leq 10^{-97}$ . The common value will be put equal to zero if  $|X_{\max}| \leq 10^{-97}$ .

- c. Y: The array of Y-ordinates, with properties corresponding to the X-ordinates, above. Y must be dimensioned at least equal to NUMPTS in the calling program.

- d. MODCURV: Controls the number of curves, and/or sets of points on one graph:
- 0 This is the only curve, or set of points, to be plotted on this graph.
  - 1 This is the first of two or more curves, and/or sets of points, to be plotted on this graph.
  - 2 This is an intermediate curve, or set of points.
  - 3 This is the last curve, or set of points, for this graph.

- e. ITYPE: Controls the type of plot (i.e., curve or point plot):
- 0 This set of points is to be represented by a curve.
  - 1 These points are to be plotted with a cross (x).
  - 2 These points are to be plotted with a plus (+).
  - 3 These points are to be plotted with a square ( $\square$ ).
  - 4 These points are to be plotted with a diamond ( $\diamond$ ).
  - 5 These points are to be plotted with a triangle ( $\triangle$ ).

f. LABEL: This is a Hollerith curve or point identifier. If a curve is being drawn, LABEL must have 4 characters (including any blanks), and these will be reproduced beside the end of the curve. This argument can be set in the calling program by a statement such as

LABEL = 4H^ONE (^ = blank)

or LABEL = 4H1234

or LABEL = 4H^ ^ ^ ^ The latter must be used when no label is wanted.

If a set of points is being plotted, LABEL is an 8-character identifier. The first 4 characters will be reproduced beside the first point, and the last four characters will be reproduced alongside the last point. This argument can be set by statements such as

LABEL = 8HFRSTLAST

or LABEL = 8H^ ^ ^ ^ ^ ONE

or LABEL = 8H^ONE^123

or LABEL = 8H^ ^ ^ ^ ^ ^ ^ ^ The latter must be used if no labels are wanted.

The above arguments, a. through f. (and q.), have meaning every time DRAW is called. On the other hand, the remaining arguments, g. through p., have no meaning except when MODCURV = 0 or 1.

- g. ITITLE: An array of twelve 8-character Hollerith words, the first six of which will form the first title line, and the last six the second. The array must be dimensioned 12 in the calling program, must contain the user's job identification, and must have unwanted characters set to blank. For example:

```
DO 1 I = 1,12
```

```
ITITLE(I) = 8H
```

```
ITITLE(1) = 8H^SMITH,^
```

```
ITITLE(2) = 8HJ.^J.^.^
```

```
ITITLE(7) = 8H^TESTIT.
```

- h. EXSCALE: X-scale in units per inch ( $10^{-99} \leq \text{EXSCALE} < 10^{99}$ ). EXSCALE will always be rounded off to one figure significance. If EXSCALE = 0, the X-scale will be computed by DRAW. This is called auto-scale.
- i. YSCALE: Y-scale in units per inch, with properties corresponding to those of EXSCALE.
- j. IXUP: Distance, in inches, of the X-axis from the bottom of the graph ( $0 \leq \text{IXUP} \leq \text{IHIGH}$ ). This argument will be ignored unless MODEXAX = 2, see below.
- k. IYRIGHT: Distance, in inches, of the Y-axis from the left of the graph ( $0 \leq \text{IYRIGHT} \leq \text{IWIDE}$ ). This will be ignored unless MODEYAX = 2, see below.
- l. MODEXAX: Determines the mode of the X-axis location:  
- 0 The X-axis will be located automatically by DRAW, with the origin of Y on the graph.

- 1 The X-axis will be automatically located by DRAW, with the origin of Y moved (in one's imagination) an integer number of inches above or below the graph, if this is appropriate. This option can be used only if the Y-scaling is automatic (YSCALE = 0).
- 2 The X-axis location will be as specified by IXUP.
- m. MODEYAX: Determines the mode of Y-axis location in the same way as MODEXAX, above, governs the X-axis location.
- n. IWIDE: Width of graph in inches ( $1 \leq IWIDE \leq 9$ ). If IWIDE is out of this range, a value of 8 will be assumed.
- o. IHIGH: Height of graph in inches ( $1 \leq IHIGH \leq 15$ ). If IHIGH is out of range, a value of 8 will be assumed.
- p. IGRID: If IGRID = 1, a 1" x 1" grid will be superimposed on the graph. This is useful only if plain paper is used on the CalComp Plotter.
- q. LAST: Indicates to the calling program whether the previous plot was completed successfully. The codes are:
  - = 0 Last plot was completed successfully
  - = 1 Last plot was not completed successfully.
  - = 2 Last plot was not completed successfully, and no further graph output will be attempted until DRAW is next entered with MODCURV = 1 or 0.
  - = 3 An attempt was made to enter DRAW with MODCURV  $\neq$  1 or 0 while the error lockout was set.
 This argument must always be a variable name and never a number in the call statement.

### 3. Notes and Comments:

- a. The graph scales and, if  $\text{MODEXAX} = 1$  and/or  $\text{MODEYAX} = 1$ , the amounts of origin offset are always output as part of the graph title.
- b. Each time a graph is completed, a message to this effect is printed on both the standard output and the console typewriter.
- c. There are internal checks of the input to DRAW to prevent incorrect use. If an input error is detected, an attempt will be made, where possible, to complete the plot. If an argument is "corrected" in this process, the user will be so informed on the standard output. If it is not possible to complete the plot, the user will be informed of the reason by a message on the standard output.
- d. If part or all of a curve would fall more than 0.6" laterally beyond the ends of the X-axis, or 0.7" vertically beyond the ends of the Y-axis, the X and/or Y ordinates will be limited so that the curve will typically become a line along part or all of the boundary of the graph as here defined.
- e. If one or more points of a point plot would fall outside the graph area, the plot of that point, or points will be inhibited. The number of such points will be reported to the user on the standard output.
- f. It should be pointed out that the X and Y scaling and axis locating processes are entirely independent, so that, for example, X might be auto-scaled, while the Y-scale is specified. At the same time the X-axis might be located automatically, while the Y-axis location is specified.
- g. It must be remembered that the scales and axis locations of a multi-plot graph are set when DRAW is called for the first time (with  $\text{MODCURV} = 1$ ). Thus the user must attempt, at that time, to achieve scaling and axis location which will be appropriate to all the plots he intends to make on the one graph. Particularly if the automatic features of DRAW are selected, foresight will be demanded of the user in this respect.

### 4. Auto-Scale Properties:

The scale factor is chosen from amongst the values 1, 2 or 5 units per inch, or some power of 10 times one of those values. A curve, or set of points which is plotted with auto-scale will normally lie entirely within the graph area as defined in 3.d., above. The only exception may occur if an axis is placed, by the user, along one edge of the graph (e.g.,  $\text{IXUP} = 0$ ,  $\text{MODEXAX} = 2$ ). In such a case, points "outside" the axis are not considered in the selection of a scale factor (e.g., negative  $X_1$  do not affect the choice of scale when  $\text{IXUP} = 0$ ). If automatic axis location as well as auto-scale is selected, the plot, if it does not fill the graph area, will be placed as far as possible towards the bottom-left of the graph area consistent with the fact that the axes can be set in increments of 1" only.

5. Space Required: 3960 cells (excluding the input arrays).
6. Temporary Storage: None
7. Error Print-Outs: There are a large number of possible error print-outs. These are all self-explanatory.
8. Error Returns: All error returns are preceded by self-explanatory error printouts. An error indication is transferred back to the calling program through the argument LAST.
9. Error Stops: None.
10. Tape Mountings: Logical Tape #8 will receive the binary graph output. The standard monitor output will receive the messages to the user.
11. Output Format: The format of the binary graph output records on magnetic tape is described in reference 1. The only difference is that in this program the interpolation option is by-passed (set to zero in the graph output record). See reference 2.
12. Selective Jump and Stop settings: None.
13. Timing: Variable, depending upon the number of points and the options chosen. Typically less than one second per curve or point plot.
14. Accuracy: The accuracy of results is equal to the resolution of the CalComp Plotter, that is, 0.01" in both the X and Y directions.
15. Equipment configuration: CDC 1604 with FORTRAN 60 compiler and Library. A CDC 160 or 160A with CalComp 165 Plotter is needed for the off-line plotting using the appropriate GRAFPLOT program.

⑤. REFERENCES:

1. Weir, Maurice D., Spritzer, Milton and McIlhenny, D. W., "160-A Graph Plot Program," Ident \*B001, SWAP Library, 15 August 1962.
2. Hogg, R. L. and Glover, D. C., "160 Grafplot Routine," Writeup available from Computer Facility, U. S. Naval Postgraduate School, 1 April 1963.
3. U. S. Naval Postgraduate School, Thesis, "Control System Programming, Remote Computing and Data Display," by Robert Lee Hogg and Dennis C. Glover, 1963.

N.B. References 1 and 2 are included in Reference 3 as Enclosures 2 and 1, respectively.

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13. ABSTRACT

This report presents an operational computer program for the minimal-time routing of single ships. Although written specifically for VC2AP3 and VC2AP2 vessels operating in a described area of the north Pacific ocean, the program can be modified easily to provide routes for other type vessels in any ocean area of the northern hemisphere. The method of incorporating weather forecasts into the preparation of minimal-time ship routes is described, and possible future developments are discussed.

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